TNO-report
TM-96-C022

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title

Behavioural aspects of Automatic Vehicle Guidance (AVG): The relationship between headway and driver comfort

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date
21 March 1996

contractor : Ministry of Transport, Public Works and Water Management
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number of pages : 25

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Rep.No. TM-96-C022

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A.P. de Vos, J. Theeuwes and W. Hoekstra

SUMMARY

Automation of road traffic may have a large potential for improving the performance of the traffic system. For the not too distant future, systems that support or automate parts of the driving task will appear on the market. On a longer term fully automated driving on parts of the road network may become possible. The acceptance of automated driving may play an important role in the feasibility of Automated Vehicle Guidance (AVG). As short headways may result in the most dramatic increase in road capacity, the Ministry of Transport, Public Works and Water Management has commissioned the TNO Human Factors Research Institute to carry out a study into the acceptability of short headways in an automated traffic system compared to manual driving. The experiment consisted of two parts with complementary methods to assess the relationship between headways and acceptability. In one part subjects gave a subjective comfort rating about the condition they were driving in, while in the other part subjects were allowed to adjust the headway to a comfortable level. Furthermore subjects drove the simulator manually before and after each AVG sessions. In the manual sessions, subjects rated the comfort level in a number of traffic conditions.

Based on the results of the experiment, recommendations were derived for the design headway of a comfortable AVG system. In order to equal the comfort level in dense traffic as experienced daily on the motorway network in rush hours, the AVG headway should be no less than 0.86 s. If it is accepted that the comfort level that occurs in incident situations would already suffice, the AVG headway could be 0.29 s.

An increase of driver comfort at very short headways was not found in this experiment (a u-shape of the comfort versus headway curve).

The preferred headways correspond to the values observed in normal traffic. Starting at a very short headway the average comfortable headway was 0.70 s, while when starting at a long headway the preferred headway was 1.46 s. On average a headway of 1.1 s was adopted.

An increase of the free driving speed after the experimental AVG sessions was found. Whether this was merely a result of driving (a simulator) for some time or whether this effect was caused by prolonged driving in AVG should be investigated in a separate experiment, including a control group that drives manually during a comparable period.

Rapport nr.: TM-96-C022

TNO Technische Menskunde
Soesterberg

Gedragsaspecten van Automatische Voertuiggeleiding (AVG): De relatie tussen volgtijd en comfort

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SAMENVATTING

Automatisering van het wegverkeer kan een groot potentieel hebben voor het verbeteren van de prestatie van het verkeerssysteem. Naar verwachting zullen in de nabije toekomst systemen op de markt komen die delen van de rijtaak ondersteunen of automatiseren. Op langere termijn zouden ook volledig geautomatiseerde systemen een rol kunnen gaan spelen. De haalbaarheid van Automatische Voertuiggeleiding (AVG) kan in belangrijke mate afhangen van de acceptatie door de gebruikers. Gezien het feit dat korte volgtijden de grootste winst in wegcapaciteit kunnen opleveren, heeft Rijkswaterstaat aan TNO Technische Menskunde opdracht verleend om een studie uit te voeren naar de acceptatie van korte AVG volgtijden, in verhouding tot normaal verkeer.
Het experiment bestond uit twee complementaire benaderingen om de relatie tussen volgtijd en acceptatie te bepalen. In één deel van het experiment gaven de proefpersonen een subjectief oordeel over een opgelegde volgsituatie. In het andere deel konden de proefpersonen zelf een comfortabele volgtijd instellen. Verder reden proefpersonen voor en na iedere AVG sessie handmatig in normaal gesimuleerd verkeer, waarbij ook een comfort oordeel gegeven werd in een aantal verkeerscondities.
Op basis van de resultaten van dit experiment zijn aanbevelingen afgeleid voor de volgtijd in een comfortabel AVG systeem. Om een zelfde comfort niveau te bereiken als dagelijks ervaren wordt in druk verkeer, dient bij AVG een volgtijd van ten minste 0.86 s aangehouden te worden. Indien het comfort niveau dat optreedt in het verkeer bij conflictsituaties als criterium wordt gehanteerd, zou de volgtijd in AVG 0.29 s kunnen zijn.
De resultaten van het experiment geven geen bevestiging voor een toename van het comfort bij zeer korte volgtijden (comfort badkuip-curve als functie van de volgtijd).
De door bestuurders ingestelde volgtijd correspondeert met de waarden die geobserveerd zijn in normaal verkeer. Wanneer een bestuurder zeer dicht bij zijn voorligger begon, werd een gemiddelde comfortabele volgtijd van 0.70 s gevonden, terwijl als de initiële afstand groot was, de wensvolgtijd op 1.46 s uitkwam. Gemiddeld was de ingestelde volgtijd 1.1 s.
De vrije snelheidskeus bleek na de experimentele AVG sessies toegenomen te zijn in verhouding tot de vrij gekozen snelheid vooraf. Of dit effect veroorzaakt wordt door het gedurende langere tijd rijden (in een rijsimulator) op een snelweg of dat dit komt door AVG, zou in een aanvullend experiment bepaald kunnen worden, waarbij ook een controle groep gedurende een vergelijkbare tijd in normaal verkeer rijdt.

1 INTRODUCTION

Automation of road traffic may have a large potential for improving the performance of the traffic system. For the not too distant future, systems that support or automate parts of the driving task will appear on the market. On a longer term fully automated driving on parts of the road network may become possible. Worldwide, a growing amount of effort is dedicated to the development of Automated Vehicle Guidance (AVG) Systems. In the United States of America the National Automated Highway Systems Consortium (NAHSC) is working towards the targets set out in the Intermodal Surface Transportation Efficiency Act (ISTEA): realisation of an Automated Highway Systems (AHS) demonstrator in 1997 and completion of the specifications for AHS by 2002. In Europe the first prototypes of fully automatic vehicles were developed within the framework of PROMETHEUS (Daimler-Benz, 1994). The Dutch Ministry of Transport, Public Works and Water Management has identified Automated Vehicle Guidance as one of the technology areas for which research and assessment should be actively supported (Ministry of Transport, Public Works and Water Management, 1994).

Based on a survey of candidate configurations for the implementation of AVG, Verwey (1995) has proposed a number of Human Factors related research items. The main issues identified are the Man Machine Interaction when transferring control between the driver and the automated system, monitoring the driver and preparing the driver for taking over manual control, the effect of prolonged automated driving on driving behaviour in manual traffic and the acceptance of automated driving. The present study addresses one aspect determining acceptance.

With Automated Vehicle Guidance (AVG), small headways as well as very accurate lateral vehicle control could be technically feasible. In this way more vehicles can pass over a narrower stretch of road. However the limits for maximum use of the infrastructure are not only set by the technical feasibility, but also by the acceptance by the road users. As short headways may result in the most dramatic increase in road capacity, this study investigates the acceptability of various headways / distances in automated traffic. One of the questions to be answered is if comfort is monotonously decreasing with decreasing distance or alternatively if comfort decreases with decreasing headways down to a certain minimum, below which comfort increases again. Comfort might be influenced by the notion that when a collision occurs at a distance near to zero, the impact speed will be very low and thus the collision energy will be very low. When comfort is plotted against headway, this effect would result in a bath-tub shaped curve.

Drivers response to decreasing vehicle separations during transition into the automated lane was investigated in the IOWA Driving Simulator (Bloomfield et al., 1995a) under the AHS programme in the USA. In this experiment subjects started as the lead vehicle of a platoon of automated vehicles. The headway to the platoon ahead was fixed at levels between 2 and 7.5 s. After some time a second vehicle entered the automated lane ahead of the simulator vehicle. This second vehicle accelerated until its speed matched the AVG-speed, during which period the distance to the simulator vehicle decreased. Subject were asked to indicate the comfort level by means of pushing or pulling a lever. The AVG-speed, the distance between platoons and the time at which the second vehicle entered the automated lane were varied. The results of this study showed that when driving in the lead vehicle of a platoon, the comfort level was positive in 89.9% of the trials. When the second vehicle entered the automated lane, in 86.2% of the trials the comfort level decreased. In 71.6% of the trials it decreased to a negative comfort level. No reference to driving in normal traffic was taken into account in this experiment.

Under contract of the Ministry of Transport, Public Works and Water Management, the TNO Human Factors Research Institute has carried out a complementary study into the acceptability of short headways in an automated traffic system compared to manually driving in traffic. This study has focussed on the headways within a platoon. For the purpose of the experiment a motorway with an automated lane was modelled in the TNO driving simulator. A database of an AVG motorway was built and the behaviour of automated traffic was modelled in the vehicle behaviour algorithms.

The experiment consisted of two parts with complementary methods to assess the relationship between headways and acceptability. In one part subjects gave a subjective comfort rating about the condition they were driving in, while in the other part subjects were allowed to adjust the headway to a comfortable level. If a bath-tub shaped comfort curve were to exist, the increasing comfort at short headways could only be expected to be found in the trials where the headway could be manually adjusted by starting not only a large distance from the preceding vehicle, but by also starting very close to the vehicle ahead. As the smoothness and precision of the automated control could have an impact on the confidence in an AVG system and thus the level of comfort, this factor was varied in the experiment. As the consequences of a collision may be felt to increase with increasing driving speed, the factor speed was also taken into account.

Furthermore subjects drove the simulator manually before and after each AVG session. In the manual sessions, subjects rated the comfort level in a number of traffic conditions. The comfort level in free driving condition should be seen as an upper boundary of driving comfort as it is today. The comfort level in dense traffic is accepted by drivers in day to day traffic and thus this level could be sufficient for an AVG system as well. The comfort level as experienced in a conflict situation, which is not uncommon in an unstable traffic flow, could set the lower limit for the comfort level that could be accepted in AVG.

2 METHOD

2.1 Experimental conditions

The experiment consisted of three parts: manual driving, AVG driving with fixed headways and AVG driving with adjustable headway.

The objective of the manual runs was to get a reference for the comfort ratings in AVG. Potentially these sessions would also give an indication of effects of AVG driving on manual

driving behaviour. During the manual runs different traffic conditions were included and presented in the following order:
- free driving
- driving in dense traffic
- a conflict situation
- driving in dense traffic.

In all conditions, the subjective judgments were registered.

Two approaches were chosen to determine the relationship between headway and driver comfort. In one part of the experiment, fixed car-following conditions were offered to the subjects. In this condition subjects were asked to give a subjective comfort rating concerning the traffic situation on a sevenpoint scale. The conditions driving speed, headway and swiftness of the approach of the platoon were varied.

The comfort rating experiment consisted of the following conditions:

Speed:	80, 105, 130 km/h
Headway:	0.01, 0.05, 0.1, 0.25, 0.5, 1.0, 1.5, 3.0 s
Swiftness of the approach of the platoon in front:	slow, swift

In the other part of the experiment subjects were free to adjust the headway that was maintained by the AVG system. Also in this part of the experiment the driving speed was varied on three levels. Furthermore the initial position from which the subjects were allowed to adjust the headway was either very close to the platoon or at a large distance. This approach was chosen to determine a possible hysteresis in headway acceptance, while starting at a very short headway would also assure that if there is a non-monotonous relation between headway and comfort, a possible comfortable situation at short headways would be detected. In order to investigate the influence of the inaccuracy in headway control that may occur in a realistic AVG system, the variability of the headways was varied on two levels. Each condition occurred twice in this part of the experiment.

The headway-adjustment experiment consisted of the following conditions:

Speed:	80, 105, 130 km/h
Initial position:	close (0.01 s), far (3 s)
Headway variability:	low, high

2.2 Apparatus

The TNO driving simulator

The experiment was carried out in the driving simulator of the TNO Institute for Human Factors. The driving simulator consists of the following three subsystems (described in detail by Van der Horst, Janssen, & Hoekstra, 1991):

- The *supervisor* computer (PC, 80486, 66 MHz DX2), which has as its tasks the communication with both the experimenter and the other subsystems, the control and monitoring of the experiment, data storage, controlling the behaviour of other traffic, etc.
- The *vehicle model* computer (PC, 80486 33MHz), which calculates the momentaneous position (X-, Y-, and FI-coordinates) of the simulated vehicle; this vehicle has the dynamic characteristics of a Volvo 240.
- The *Computer Generated Image* system (CGI, Evans & Sutherland ESIG 2000), which generates real-time images (refresh frequency 60 Hz, update frequency 30 Hz).

During experiments, the subject is seated in a fixed base mock-up of a Volvo 240 and has all normal controls (steering wheel, accelerator, brake, etc.) at his disposal. Based on the control signals, the vehicle model computes the momentaneous state of the vehicle model. An elaborate description of this model is given by Godthelp, Blaauw and Van der Horst (1982). Feedback of steering forces is given to the driver by means of an electrical torque engine, and of sound by an electronic sound generator (noise of engine, wind, tyres, indicator, horn, other traffic, etc.). The momentaneous position (X,Y) and heading angle (FI) are transmitted via the supervisor to the visual scene computer. The CGI system computes the visual scene as seen from the position of driver. This image is projected on a screen in front of the mock-up by means of three high-resolution BARCOGRAPHICS 801 projectors (visual angles of separate projectors: 40° horizontally, 30° vertically).

AVG motorway

A three lane motorway was modelled. The design of the AVG system was consistent with systems that are being studied in other projects (Bloomfield et al., 1995a,b, Verwey, 1995). On the right and middle lane, traffic drove under normal manual control. The left lane was a dedicated AVG lane. The AVG lane had the following characteristics:
- the road surface was brown;
- there were double road markers between the AVG lane and the manual lanes. These markers had a 9−3 pattern (the lines were 9 m long, while the gap between the lines was 3 m);
- the AVG lane was 3 m wide (the manual lanes were 3.6 m wide);
- matrix signs mounted on gantries above the AVG lane indicated a dedicated lane symbol (diamond shape) with a capital "A" within.

Figs 1 and 2 illustrate the AVG situation respectively at a long headway and at a very short headway.

In all conditions a speed limit of 100 km/h was shown on matrix signs above the manual lanes.

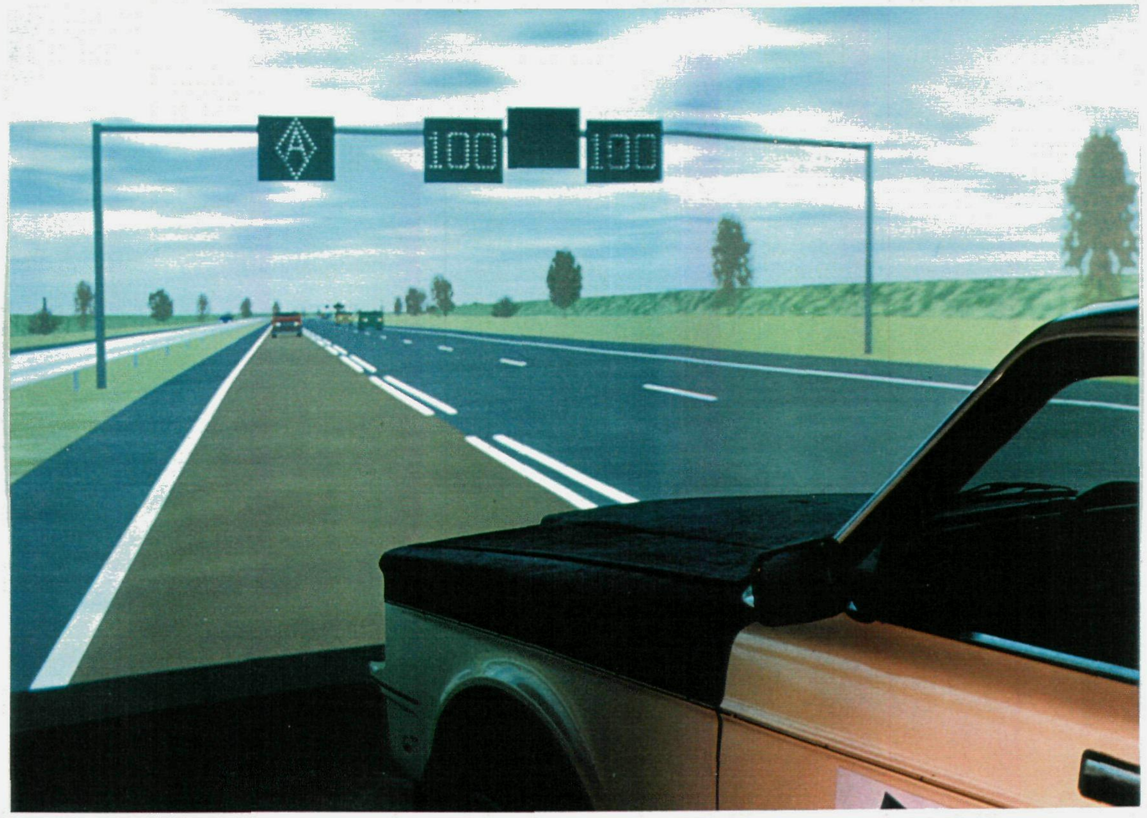

Fig. 1 AVG driving at a headway of 3 s.

Fig. 2 AVG driving at a headway of 0.01 s.

AVG vehicle

Within the simulator mock-up the status of the AVG system was indicated by means of lamps in the dashboard. One green light indicated the AVG system was active. Two green lights indicated that the AVG system was locked on the platoon in front of the vehicle. When the AVG system was on, there was neither the need nor the possibility for the driver to control the course or speed of the vehicle. The feedback forces on the steering wheel and the accelerator were reduced during AVG driving. A red lamp in the dashboard was used to indicate to the subject that she/he should do something, either to give a subjective rating, or to adjust the headway to a comfortable situation.

AVG traffic

When the vehicle was driven in the AVG lane the system automatically took over control (Bloomfield et al., 1995b). A likely procedure is that a vehicle moves in, in front of a platoon of cars. However, in this way it would take considerable time before a platoon would be formed in front of the subject. Therefore, after moving into the automated lane, the subject saw a complete platoon of cars in the far distances. After a few seconds the platoon was slowed down until it reached a specific headway relative to the simulator vehicle. As soon as a particular condition was completed the platoon moved away to the manual lanes and a new platoon moved in front of the simulator vehicle. Further on in this report the procedure of a platoon moving in front of the simulator vehicle until moving away again is referred to as a 'trial'.

The realistic impression of the AVG traffic was enhanced by small, naturally varying, disturbances of the lateral position of the AVG vehicles.

Comfort rating interface

By means of a button board, subjects gave a subjective rating about the present driving situation. This box was mounted to the right side of the steering wheel at an easy reaching distance from the subject (see Fig. 3). There were seven buttons: three green ones on the right side, three red ones on the left side and a half green / half red button in the middle (as indicated in Fig. 4).

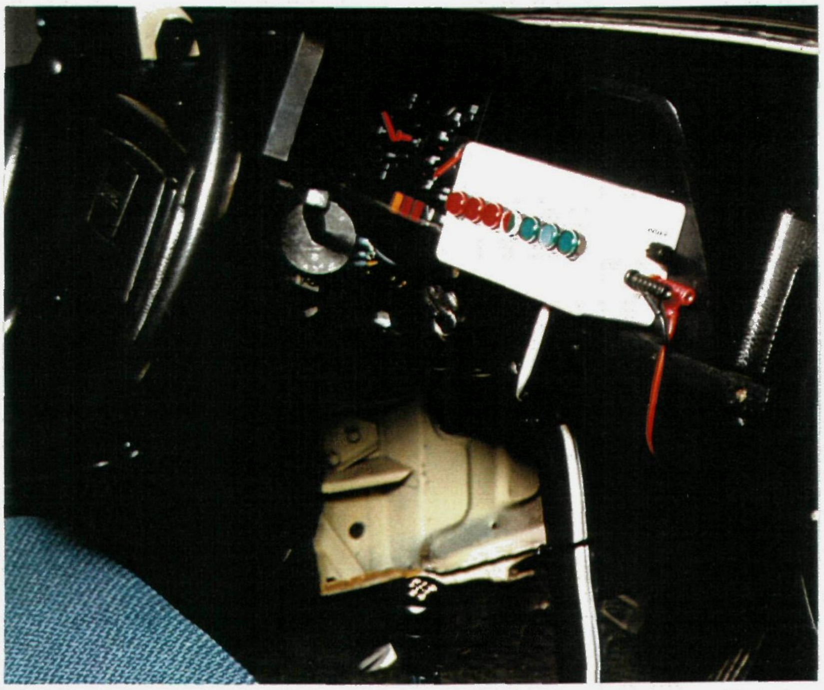

Fig. 3 Comfort rating box mounted in the driver compartment of the simulator.

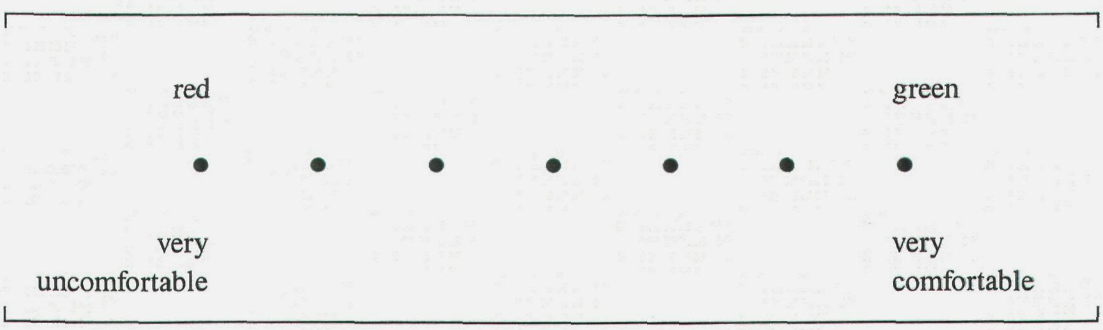

Fig. 4 Seven point comfort rating scale.

Headway adjustment

Subject were able to adjust the headway by means of a tumble switch to the right of the driver. Pressing this forward reduced the headway, while pressing it on the back increased the headway. Subjects could adjust the headway continuously over a range between 0.01 and 3.0 s. When a subject was content with the chosen headway, this was confirmed by pushing any of the green or red buttons (subjects were specifically instructed that this confirmation was not to be considered as a rating).

2.3 Subjects

In a timespan of one and a half week, a total of 16 subjects participated in the simulator experiment. Both male (9) and female (7) subjects participated. The choice of this relatively large number of subjects was based on the notion that subjective ratings may show a relatively high variance. For the same reason a within subject experimental design was chosen. Subjects were selected on the following criteria: age between 21 and 45 years, in the possession of a driving licence for more than 3 years and driving more than 10,000 km per year. All male subjects had previous experience in the TNO driving simulator. The number of female subjects in the TNO database who have driven the simulator before was limited, so also subjects without previous experience participated. The latter group was allowed to get acquainted with the simulator before the experiment started. All subjects completed the experiment. The subjects were paid for their participation.

2.4 Procedure

Each subject participates in two half day sessions; one for comfort ratings and one session for headway adjustment. Each subject did the two sessions on separate days, to avoid inattention or boredom. Two subjects participated in parallel, alternating every 20 minutes. Before each session, subjects read a written instruction (see Appendix A), which was repeated verbally when the subjects were seated in the simulator. The AVG system and the motorway was explained. Subject were forewarned that traffic jams and breakdowns of the AVG system might occur. With respect to the comfort ratings, subjects were asked to reflect their impression of the separation to the preceding vehicles and the way this was established.

In the AVG-runs, subjects started in the right lane. They were instructed to speed up in the right lane and to steer into the AVG-lane, after which the control of the vehicle was automatically taken over by the system. Subjects were allowed to take their hands and feet off the controls, as even in breakdown situations they could not intervene, i.e. the system was in full control.

Manual runs

Each session was started and ended with a run in manual driving mode. With regard to the manual runs the subjects were instructed to stay within the right lane, while in dense traffic they were allowed to pass other vehicles in the left lane. Furthermore subjects were instructed to choose their speed and headway like they would normally do, e.g. to drive to work. The speed limit (100 km/h) was brought to the attention of the subjects. In the manual run, drivers started at an empty road; after 5 km subjects were prompted to give a subjective rating of the driving condition. This rating on an empty road gave the upper limit of what subjects considered as comfortable. A little further on they encounter slow moving traffic which speeded up after the subject had joined behind. For the next 5 km subjects drove in dense traffic conditions (see Fig. 5) after which a subjective rating was asked. At the beginning of the last 5 km a conflict situation occurred; the preceding vehicle suddenly decelerated at a rate of 6 m/s^2. Shortly after, the subjects gave their rating and traffic started moving again. Finally a comfort rating in dense traffic was given again 5 km onwards.

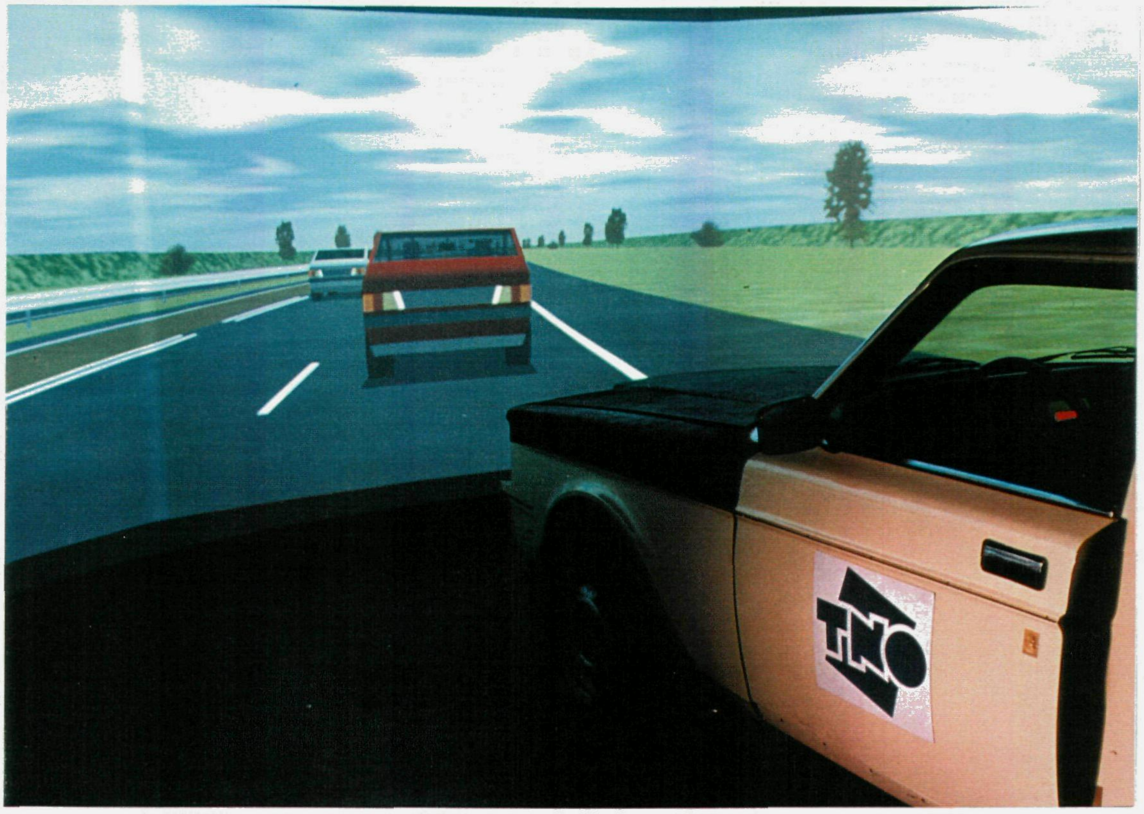

Fig. 5 Dense traffic during a manual driving run.

Comfort rating session

In the comfort rating session each subject drove 6 experimental runs of about 20 minutes. Each run contained all 8 headway conditions. The order of the headways was based on a digram balanced Latin square. The speeds were blocked: during a run the speed was kept constant. The order of the speeds was balanced between subjects. The control algorithm determined the rate at which the platoon closed in on the subject before the simulator vehicle was locked onto the platoon. This condition was pseudo-randomly attributed in such a way that all conditions occurred once.

In each run a catch trial was added. This was done to give subjects a realistic idea of the fact that also in AVG systems may break down. In a catch trial the AVG platoon suddenly came to a halt. After a catch trial a dummy trial was done to smooth out the effect of this sudden experience. In total a run consisted of 10 trials.

The 6 experimental runs were preceded by a practice run (this run was the same run as the last one).

Subjects were explicitly instructed to consider both the approach and the steady state following situation in their judgment. The comfort ratings were given after one minute of steady state following.

Headway adjustment session

In the headway adjustment session, eight experimental conditions were offered in one run. During a run the speed was constant. The order of the speed levels was balanced between subjects. In half of the trials the subject started adjusting the headway from a very close starting point (0.01 s headway), while in the other half the starting point was very far (3 s headway) from the preceding AVG vehicle. Furthermore the accuracy of the headway control was an experimental variable. In half of the trials the AVG system controlled the headway very accurate, resulting in a very low headway variability. In the other half of the trials the accuracy was low, with a corresponding high variability of the headway. The order of the starting position and the order of the headway variability were balanced. Also in these runs catch trials were added, followed by a dummy trial.

In total there were 3 experimental runs (of 10 trials each), preceded by a practice run (this run was the same run as the last one).

2.5 Data collection and analysis

During the comfort rating sessions and the manual runs the scores on the seven point scale were recorded. In order to compensate for the differences between subjects in their absolute level of ratings and the differences in the range of the ratings, a z-transformation per subject was applied.

The comfort ratings of the manual runs were transformed conform the z-transformation of the automatic runs, i.e. this z-transformation is the comfort rating minus the average rating of a subject in the automatic runs, divided by the standard deviation of comfort rating over the automatic runs. In this way the scale for the manual comfort ratings was the same as the scale for the ratings in the automatic runs.

The separation as adjusted by the subjects was recorded in terms of time headway at the moment that the subjects gave their confirmation that they were ready.

In the manual runs the free driving speed was registered starting at 2 km from the beginning of the route. The speed was averaged over a distance of 2 km.

3 RESULTS

3.1 Comfort ratings

3.1.1 Automated traffic

An analysis of variance (ANOVA) was performed on the comfort ratings with factors approach (swift, slow), speed (80, 105, 130) and headway (0.01, 0.05, 0.1, 0.25, 0.5, 1.0, 1.5, 3.0). Only the factor headway showed a main effect [$F(7,105)=65.8$, $p<0.001$]. The effects of speed and approach were not significant (respectively [$F(2,30)=3.01$, n.s.] and [$F(1,15)=1.71$, n.s.]). In a separate analysis the factor gender (male, female) was taken into account in an ANOVA of the comfort rating without z-transformation. Neither a main effect of the factor gender was found [$F(1,12)=0.62$, n.s.], nor any significant interactions with other factors.

Fig. 6 shows the z-transform of the comfort ratings as a function of the headway, for all three speeds. The relationship between comfort rating and headway is monotonous, without any sign of a tendency towards increased comfort at very short headways. This indicates that the hypothesis, that due to the small effects of collisions at very short headways these headways are still acceptable, should not be accepted for this configuration.

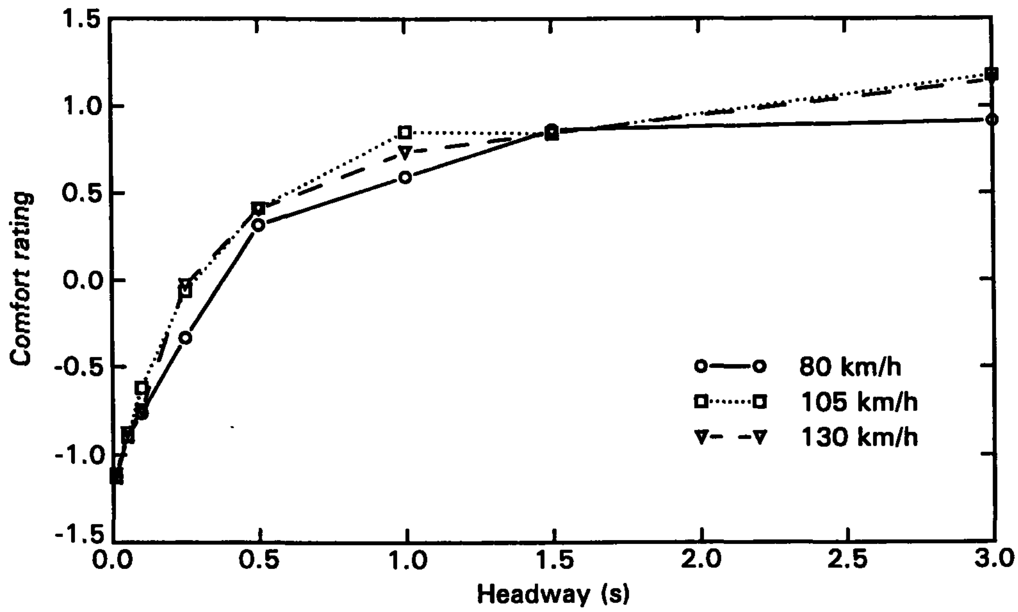

Fig. 6 Comfort rating (z-transform) as a function of the time headway for three speed levels (80, 105, 130 km/h).

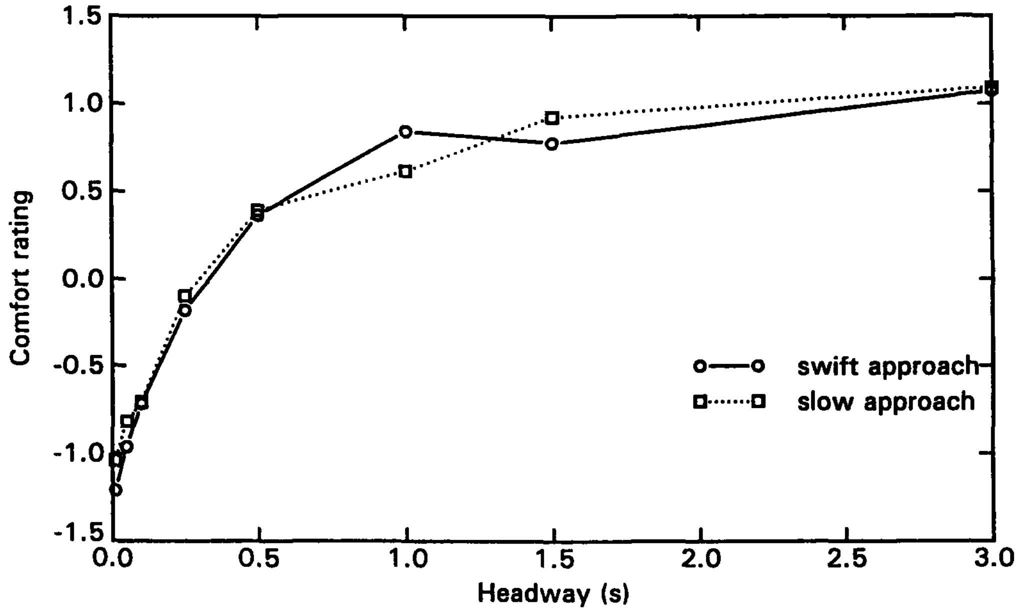

Fig. 7 Comfort rating (z-transform) as a function of the time headway for two approach speeds (slow, swift).

The comfort ratings as a function of headway for the two approach conditions are given in Fig. 7. Although subjects were explicitly instructed to consider both the approach and the steady state following situation in their judgment, the comfort rating given after one minute of steady state following shows no effect of the swiftness of the approach.

3.1.2 Manual driving

An ANOVA was performed on the z-transformed comfort rating in manual traffic with the factors run order (before the first AVG session, after the first AVG session, before the second AVG session, after the second AVG session) and the traffic situation (free driving, dense traffic, conflict situation, dense traffic after the conflict situation). A main effect of the traffic situation was found [$F(3,45)=26.2$, $p<0.001$]. No main effect of run order was found [$F(3,45)=0.34$, n.s.]. Fig. 8 gives the average comfort ratings for the four traffic situations.

When subjects drove in the manual mode, they did not always follow the preceding vehicles (despite the instruction). Headways in the order of 7 seconds occurred. As a consequence the conflict situation that was part of the manual ride was not always perceived as such, since the preceding vehicle slowed down a long way ahead of the subject so the subject was only confronted with a traffic jam. However for the purpose of the comfort ratings the impression of hectic traffic in general remained. Reaction times could not be determined when there is no car following situation preceding the conflict. Also subjects sometimes chose very short headways in manual driving, in a few cases even resulting in a collision when the incident occurred (predecessor decelerated at 6 m/s^2).

Fig. 9 presents the average comfort levels as a function of headway as found in AVG. Indicated by horizontal lines are the comfort ratings in the manual runs. The points of intersection between the comfort levels in manual traffic and the AVG comfort curve were determined. The comfort rating of manual driving in dense traffic corresponds to a headway of 0.86 s in automated traffic, while the comfort rating just after the conflict situation in manual traffic corresponds to a headway of 0.29 s in the automated mode. For large headways the comfort rating in AVG seem to asymptotically approach the comfort level of free driving in manual traffic.

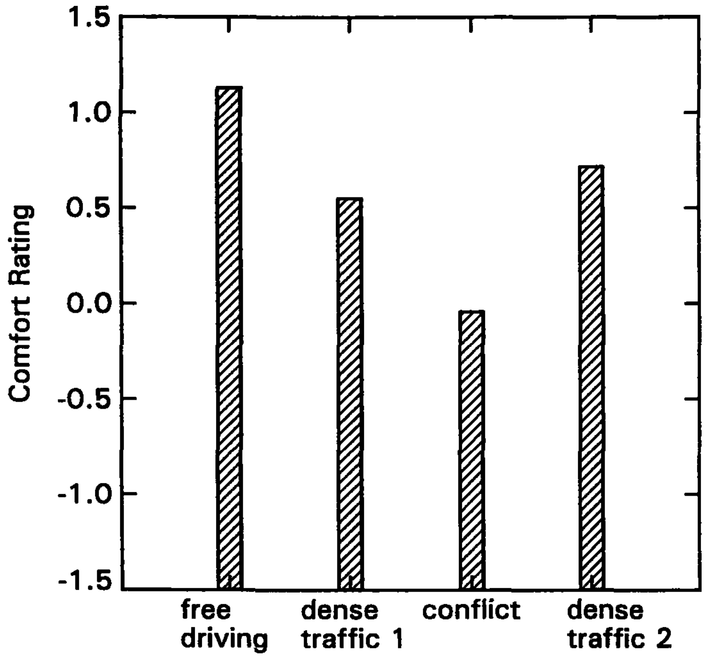

Fig. 8 Comfort ratings during manual driving.

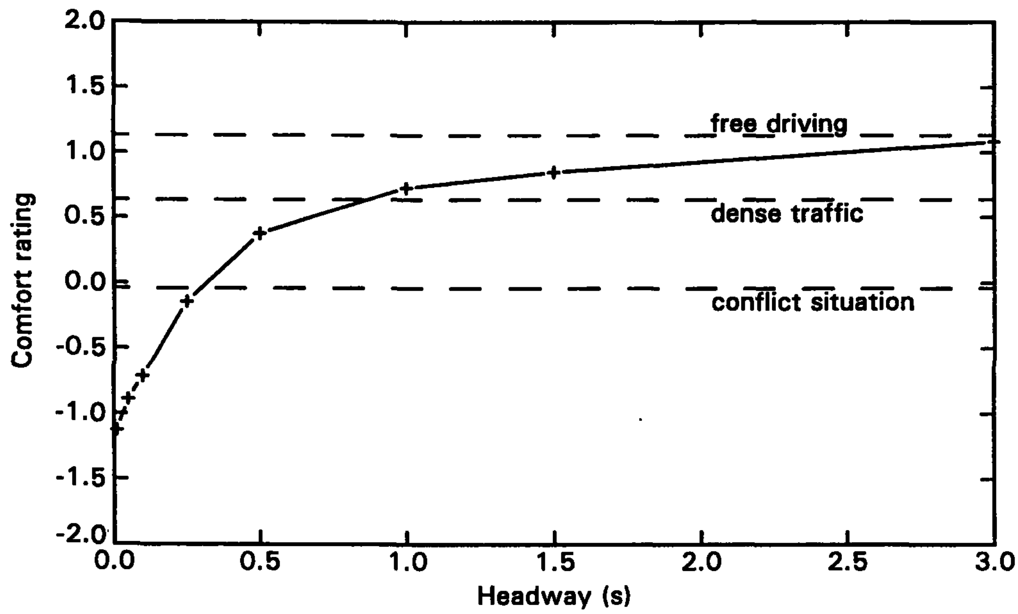

Fig. 9 Comfort ratings in both automated traffic and in manual driving.

3.2 Preferred headways

The factors speed (80, 105, 130), initial position (close, distant) and variability (low, high) were taken into account in an ANOVA of the preferred headway. A main effect of the initial position was found [$F(1,15)=19.4$, $p<0.001$]. Furthermore there is a tendency towards longer preferred headways in the high variability condition [$F(1,15)=3.41$, $p<0.1$]. Speed had no effect on the preferred headway [$F(2,30)=0.963$, n.s.]. In a separate analysis the factor gender (male, female) was taken into account. Neither a main effect of the factor gender was found [$F(1,12)=0.0007$, n.s.], nor any significant interactions with other factors.

Fig. 10 shows the difference in preferred headway for the two initial positions and for both high and low headway variability. Starting at a very short headway, subjects choose an average comfortable headway of 0.70 s, while when starting at a long headway subjects only closed in on the preceding vehicle to a headway of 1.46 s, so there is clearly a hysteresis in the preferred headway. On average a headway of 1.1 s is adopted.

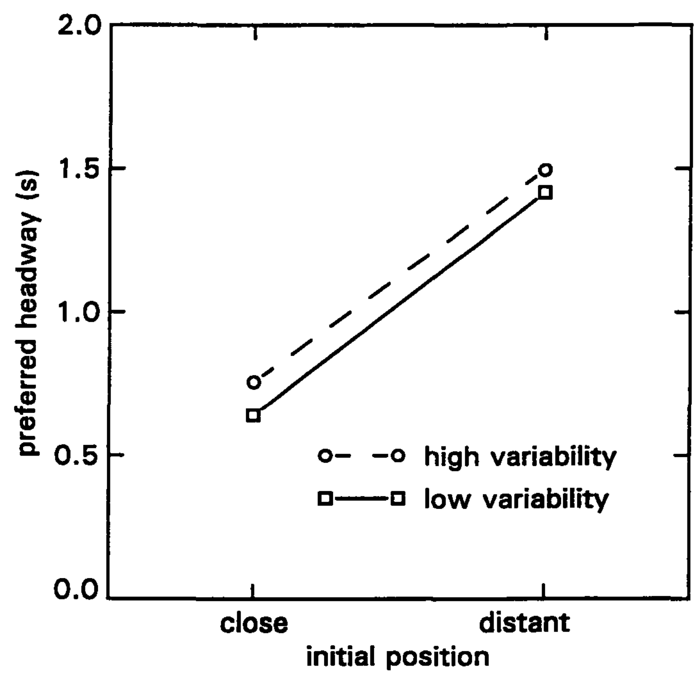

Fig. 10 Preferred headway for close and distant initial position and at high and low headway variability.

Fig. 11 shows the preferred headway as a function of speed. This confirms that subjects do have a notion of headway (instead of just distance) to control a comfortable situation, that is they are able to keep constant the time between the moment the preceding vehicle passes a certain point and the time their own vehicle passes that point. When the headway is transformed into a following distance, an ANOVA confirms a significant effect of driving speed [$F(2,30)=18.6$, $p<0.001$].

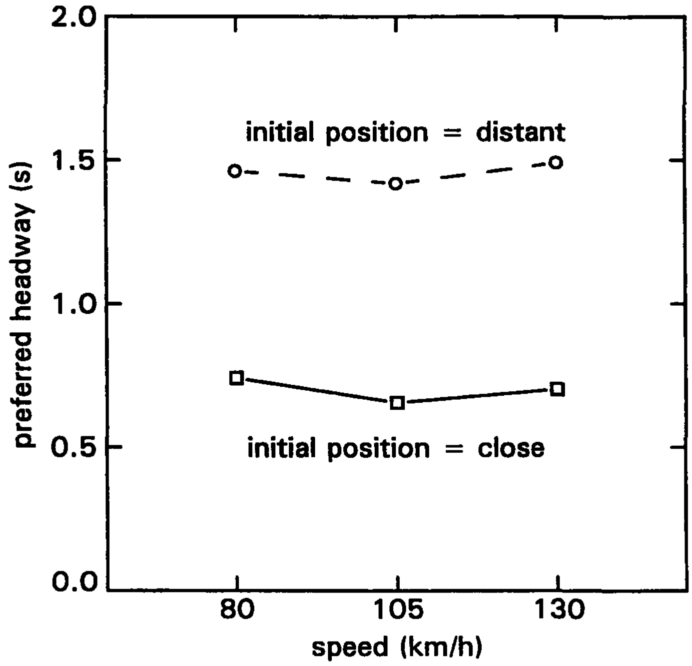

Fig. 11 Preferred headway as a function of driving speed for both a distant initial position and a close initial position.

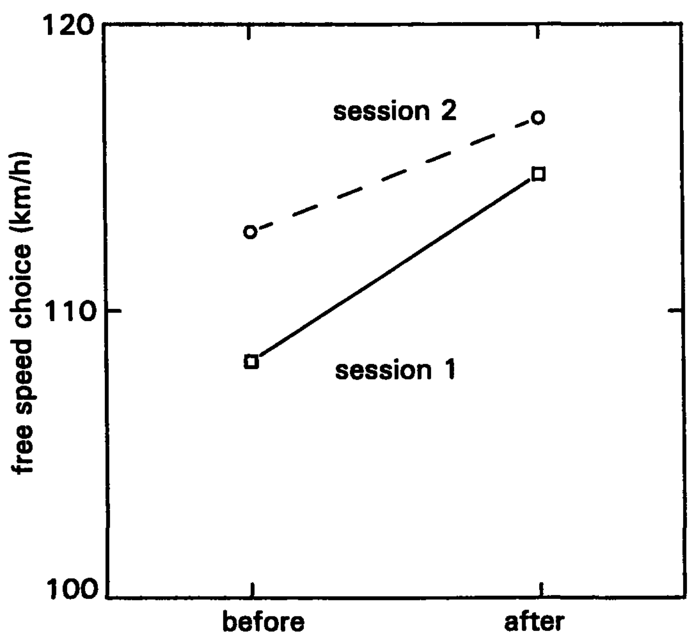

Fig. 12 Free driving speed choice in the manual runs before and after the first and the second AVG session.

3.3 Free driving speed

In order to get a first idea about the possibility that AVG may induce drivers to adapt their behaviour in normal manual driving afterwards, the speed choice in the free driving situation of the manual runs was analyzed by means of an ANOVA taking into account the factor run order (before the first AVG session, after the first AVG session, before the second AVG session, after the second AVG session). This showed a main effect of run order [$F(3,45)= 5.38$, $p<0.01$], which is illustrated in Fig. 12.

4 DISCUSSION AND CONCLUSIONS

Based on the present results the recommendations can be derived for the design headway of a comfortable AVG system. In order to equal the comfort level in dense traffic as experienced daily on the motorway network in rush hours, the AVG headway should be no less than 0.86 s. If it is accepted that the comfort level that occurs in incident situations would already suffice, the AVG headway could be 0.29 s. For the eventual acceptance, other factors may also play a role, i.e. costs of an AVG system, whether there are other compensating comfort aspects like being able to work or to relax during an AVG journey, reduced travel times or how long a certain condition is maintained (a relatively low comfort level may be acceptable at bottlenecks in the road network), etc. Furthermore the discomfort as experienced at short headways may reduce after some time when people get used to the situation.

An increase of driver comfort at very short headways was not found in this experiment (a u-shape of the comfort versus headway curve). When the hypothesis that at short headways the chance of a collision is high but the collision energy is low is reconsidered, it might be possible that, given a normal vehicle, even a collision with low impact speed is undesirable, i.e. it results in a bump and even light damage on the vehicle. For this reason a different result may be found if the short distance is realised by means of a mechanical coupling or when a collision buffer is mounted at the front of the vehicle.

The results of the headway adjustment trials seem to correspond to the values observed in normal traffic. Starting at a very short headway the average comfortable headway was 0.70 s, while when starting at a long headway the preferred headway was 1.46 s. On average a headway of 1.1 s was adopted. In an overview given by Van der Horst (1993) a wide range of average headways is reported: when close following was encouraged (subject driving an instrumented vehicle) an average headway as low as 0.46 s was found, while spot observations on a motorway showed average headways in the right lane of 2 s. In an experiment where an instrumented vehicle moved closely in front of another vehicle the headway of the following vehicle was restored to only 0.81 s, while the headway was 1.41 s on average before the vehicle cut in front (Van der Horst & Bakker, 1991). The results in the latter experiment have a great resemblance with the results of the two initial position conditions in the AVG experiment.

Whether the increased free driving speed at the end of the experimental sessions was influenced simply by driving (a simulator) for some time or whether this effect was caused by driving in automated traffic cannot be determined from the present experiment, as no control group drove during the same period in manual traffic. Although the average speed in the automated sessions was 105 km/h, the experience of driving 130 km/h in one out of three runs may inspire subjects to adopt a higher speed afterwards in the manual runs. The effect of prolonged AVG driving on the choice of speed and headway in manual driving should be investigated in a separate experiment. Such a study could be part of a research programme as proposed by Verwey (1995).

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Soesterberg, 21 March 1996

Ir. A.P. de Vos

APPENDIX A Instruction

INSTRUCTIE AAN PROEFPERSONEN

Algemeen

U gaat een aantal ritten maken in de rijsimulator op een snelwegtraject.
In de auto is schakelen niet nodig. Ook hoeft U geen richting aan te geven.
De linker strook op de snelweg is een bijzondere strook: in deze strook wordt uw voertuig volledig automatisch bestuurd. Zowel het gas geven als het sturen wordt door een computer gedaan. U mag daar het stuur en het gas loslaten.
Dit wordt Automatische Voertuiggeleiding ofwel AVG genoemd.

In de rechter twee rijstroken rijdt het verkeer zoals u dat gewend bent. In de linker rijstrook worden auto's automatisch bestuurd.
U zult zowel ritten maken waarbij U gewoon zelf moet rijden, als ritten waarbij een automaat uw auto bestuurt.

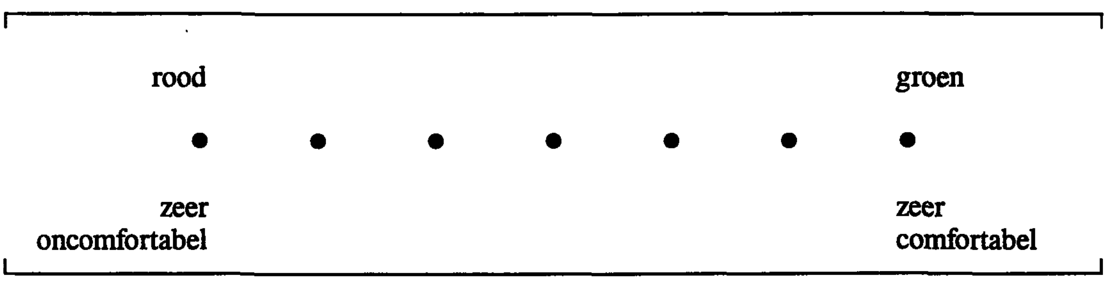
Handmatig rijden

In de ritten waarbij U zelf rijdt dient U in de rechter rijstrook te blijven. Verandert U niet van rijstrook.
Kies uw snelheid en afstand tot voorliggers zoals u dat normaal ook zou doen, bijvoorbeeld om naar uw werk te gaan. U moet zich aan de maximum snelheid houden. Wanneer U met het verkeer meerijdt mag U rechts passeren.

Zo af en toe gaat er op het dashboard een rood lampje branden. Zodra dit rode lampje brandt, dient U aan te geven wat U vindt van het stuk dat U net heeft meegemaakt.

U geeft dit aan door middel van de rode en groene knoppen rechts naast het stuur. Doe dit vlot en ga af op de indruk die de situatie oproept.
U kunt steeds maar één reactie geven, herstel is niet mogelijk.

De linker knoppen zijn rood, de rechter zijn groen:



Van links naar rechts betekenen de knoppen:
- zeer oncomfortabel,
- tamelijk oncomfortabel,
- enigszins oncomfortabel,
- gemiddeld,
- enigszins comfortabel,
- tamelijk comfortabel,
- zeer comfortabel.

Instructie voor de AVG comfort rating sessies

In de ritten waarbij U in de automatische linker rijstrook moet rijden, maakt U snelheid op de rechter strook en stuurt U de auto rustig naar de linker rijstrook. De besturing wordt dan vanzelf overgenomen.

Als de automatische besturing aan staat gaat er een groen lampje op het dashboard branden. U hoeft dan niet meer te sturen of gas te geven.

U zal aansluiten bij een groepje auto's (een peleton) dat ook onder automatische controle staat. Zodra U aangesloten bent bij de groep gaat een tweede groen lampje branden.

Na enige tijd gaat een rood lampje branden. Zodra dit rode lampje brandt, dient U aan te geven hoe comfortabel U het rijden vindt bij deze afstand tot uw voorligger.

U geeft dit weer aan door middel van de rode en groene knoppen rechts naast het stuur.

Samengevat betekenen de lampjes op het dashboard:

1 groen lampje	= AVG is aan
2 groene lampjes	= U bent aangesloten bij het groepje voor U
rood lampje	= geeft uw oordeel.

U rijdt verschillende ritten met verschillende snelheden. Tijdens ritten varieert de afstand die gehouden wordt tot uw voorligger. Ook varieert de snelheid waarmee U achter een groepje aansluit.

Bedenk bij het geven van uw oordeel dat het gaat om de afstand tot uw voorligger. Bedenk ook dat de auto automatisch bestuurd wordt door een computer.

NB: Houdt U rekening met files en pechgevallen.

Instructie voor de afstand instelsessies

In de ritten waarbij U in de automatische linker rijstrook moet rijden, maakt U snelheid op de rechter strook en stuurt U de auto rustig naar de linker rijstrook. De besturing wordt dan vanzelf overgenomen.

Als de automatische besturing aan staat gaat er een groen lampje op het dashboard branden. U hoeft dan niet meer te sturen of gas te geven.

U zal aansluiten bij een groepje auto's (een peleton) dat ook onder automatische controle staat. Zodra U aangesloten bent bij de groep gaat een tweede groen lampje branden.

Na enige tijd gaat een rood lampje branden. Zodra dit rode lampje brandt, dient U zelf een comfortabele afstand tot uw voorligger in te stellen. Dit doet U door middel van de kantel-schakelaar op de middenconsole. Door naar voren te drukken gaat U dichter naar uw voorligger; door naar achter te kantelen wordt de afstand groter.
Als U klaar bent met instellen, druk dan op een willekeurige rode of groene knop.

Samengevat betekenen de lampjes op het dashboard:

1 groen lampje	= AVG is aan
2 groene lampjes	= U bent aangesloten bij het groepje voor U
rood lampje	= stel een comfortabele afstand in.

U rijdt verschillende ritten met verschillende snelheden. Tijdens ritten varieert de begin-afstand voordat U de afstand in kunt stellen. Ook varieert de afstand in verschillende mate.

NB: Houdt U rekening met files en pechgevallen.